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SYSTEMATIC ASYMMETRY OF CREST LINES IN THE HIGH SIERRA OF CALIFORNIA.[1]

THE substance of the present paper was communicated to the Section of Physiography of the Congress of Arts and Science at St. Louis last September. The section had just listened to Mr. Johnson's paper on "The Profile of Maturity in Alpine Glacial Erosion" (this JOURNAL, pp. —). Mr. Johnson stated that since his first observations in the Sierra in 1883 his ideas as to the explanation of the phenomena had undergone development, and he regretted that he had been unable to revisit the region for purposes of verification. It was therefore a matter of gratification that I was able to supplement his presentation by the statement that during two seasons of exploration in the glaciated district of the Sierra I had found his hypothesis of cirque development by glacial sapping of the utmost utility in the explanation of the topography. It happened also that its utility was illustrated in my discussion of the origin of the special features to which my own communication referred.

In the higher part of the Sierra Nevada the glacial cirque is a conspicuous feature of the topography. Each main crest of the great mountain mass, as a rule, is bordered on each side by a row of cirques facing outward. Separating the cirques on the same side of the main ridge are subordinate ridges or spurs. Gradually the cirques unite to form glacial troughs, and these troughs are separated, at a somewhat lower level, by ridges constituting subordinate features of the range. Some of the ridges between cirques and between troughs are equally steep on both sides of their crest lines, but many —a large minority—are notably steeper on one side than on the other, and this asymmetry of cross profile is definitely related to the cardinal points. Ridges trending east and west are steeper on the north side than on the south, those trending north and south are steeper on the east side, and those trending northwest and southeast are steeper on the northeast side. In general, the gentler slope has the grade of a steep roof, and it is often clothed by rock fragments approximately

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in situ. Ordinarily it is too steep for the horse, but is readily scaled by the mountaineer. As a rule, the steeper slope either is constituted by, or else includes, an abrupt cliff which at most points cannot be climbed. Fig. 1 shows a group of high ridges in which the steeper faces are turned to the north, and Fig. 2 a group in which they are turned to the northeast.

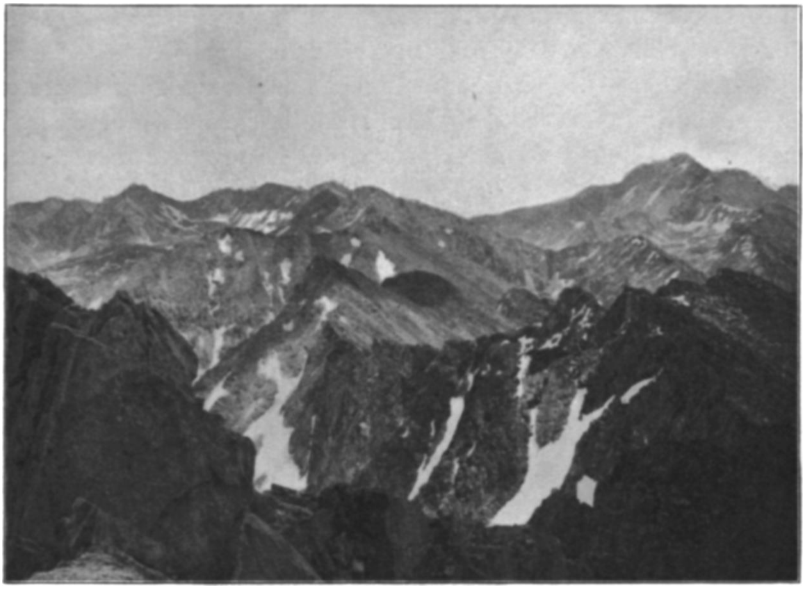

FIG. 1.—Eastward from Mount Gardiner, Sierra Nevada. Compare the southward (right) slopes with the north-facing cliffs. [Photograph by J. N. Le Conte.]

These slopes are not controlled by rock structure. The principal rock is granite, and this granite is in large part structureless. Where it is traversed by joint systems the details of sculpture are greatly influenced by the joints, but the trend and slope of the greater features are independent of the joints.

A little reflection shows that the distribution of steep slopes is correlated with the alimentation of Pleistocene glaciers. The southward slopes of the east-west ridges, because turned toward the sun, lost more snow by melting and evaporation than did the northward slopes, and a smaller fraction of the snowfall they received remained to nourish glaciers. Thus the glaciers resting against the southward slopes were comparatively ill fed, and the glaciers of the northward slopes were comparatively well fed. The north-south ridges may be assumed to have been swept, then as now, by dominant westerly winds, which carried much snow from the westward slopes over the crests to the eastward slopes, where it accumulated; and thus the glaciers resting against the eastward slopes were better nourished than those of the westward. These peculiarities of snow distribution may be readily observed at the present time. If one stands, late in summer, upon a peak in the midst of the glaciated district and looks toward the east or north, he sees bare rock, with only here and there a small remnant of snow; but if he turns toward the west or south, he looks upon a patchwork of snow and rock in which the predominance of the rock may not at once be apparent. Fig. 7 illustrates the relations of surviving snowbanks in early summer to northward and southward slopes.

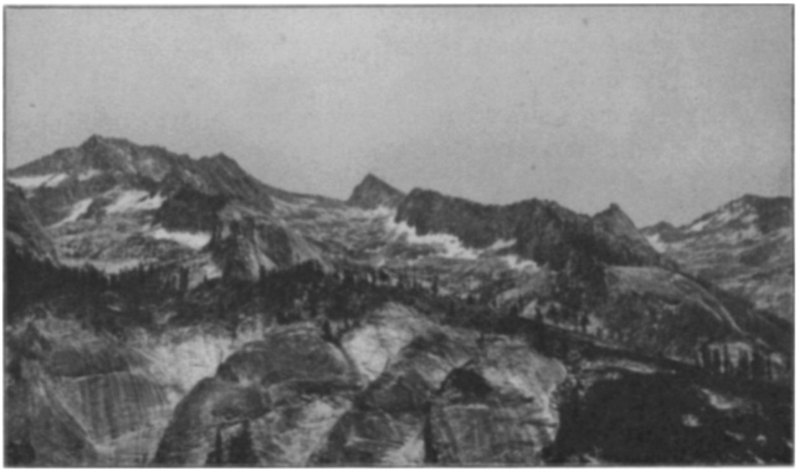

FIG. 2.—Southeastward from Alta Meadows, Sierra Nevada. Compare the northeast-facing walls of the high glaciated valleys with their southwest-facing walls.

It can hardly be doubted that the distribution of Pleistocene snow deposition stands in causal relation to the distribution of asymmetry in the crest lines of the minor ridges. And it is in explanation of this relation that I avail myself of Johnson's hypothesis. Each glacier which receives more snow on one side than on the other adjusts its cross profile to a condition of equilibrium by moving away from the region of greater supply to the region of lesser supply. This lateral motion is, of course, combined with the general, and more rapid, forward motion of the glacier, but it is nevertheless competent to produce at the side of the glacier phenomena quite similar to those at the head. Fig. 3 shows diagrammatically the ground plan of a glacier flowing southward. The greatest snow accumulation is in the cirque, *AA*, where precipitation is at a maximum, where depletion through solar influence is at a minimum, and where circling cliffs protect against removal by the wind. There is great accumulation also along the west margin, *BB*, where the snow drifted by the westerly winds comes to rest in the shelter of the west wall of the glacier trough. Along the eastern border, *CC*, the snow deposit is comparatively small, because of exposure to the westerly winds. The resulting lines of ice-flow are as drawn. Moving directly away from the walls of the cirque, the glacier makes and annually renews the bergschrund, *ab*. Moving obliquely away from the west wall of the trough, the glacier similarly produces the minor bergschrund *bc*, and this minor bergschrund leads to sapping and the production of a cliff, just as the major bergschrund causes the cirque cliff. Thus the west wall of the trough is kept steep, and is thereby contrasted not only with the east wall of the same trough, but with the east wall of the adjacent trough, so that the rock crest between the two troughs is not symmetric.

Usually in viewing a cirque it is possible to trace about its wall a somewhat definite line separating a cliff or steeper slope above from a gentler, usually scalable, slope below. This line I conceive to mark the base of the bergscrhund at a late stage in the excavation of the cirque basin. I have called it in my notes "the schrund line." It can usually be traced for some little distance beyond the cirque, and sometimes for several miles on one wall or other of the glacier trough. Advancing along the trough wall, it descends gradually with a slope which may be assumed to represent the gradient of the ice surface, that surface having been somewhat higher than the schrund line. Its expression outside a cirque may be seen in Figs. 2, 5, and 6.

At a somewhat lower level than that to which the preceding para-

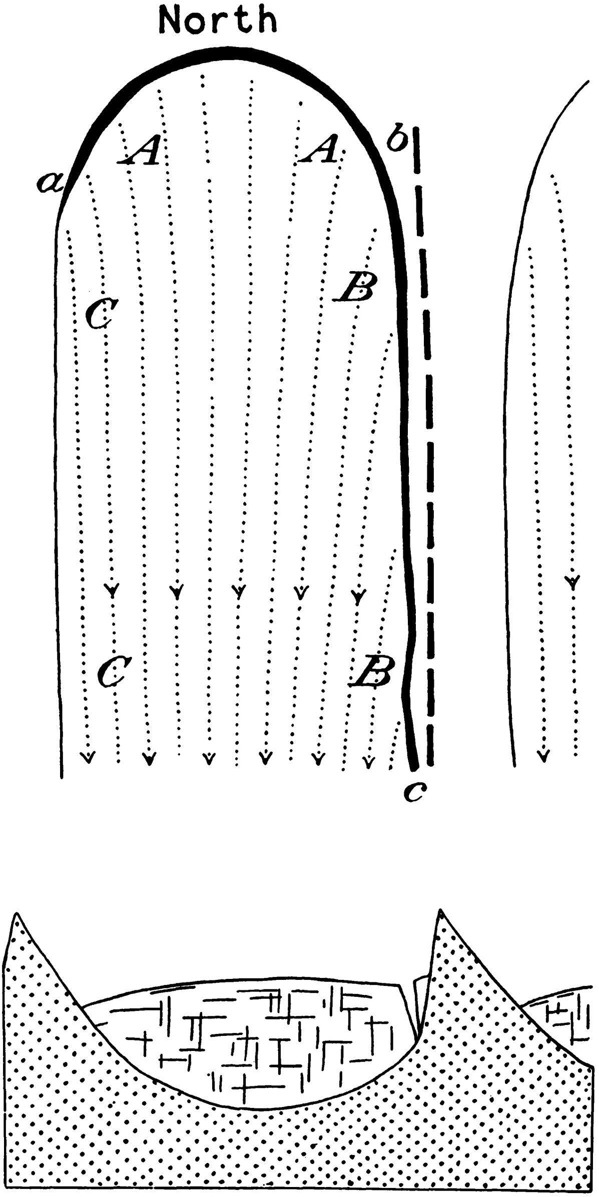

FIG. 3.—Diagrammatic ground plan and section of a glacier. The heavy line *abc* marks the position of the bergschrund. Dotted lines show direction of ice flow. The broken line marks the crest of the spur separating the glacier from its neighbor on the west.

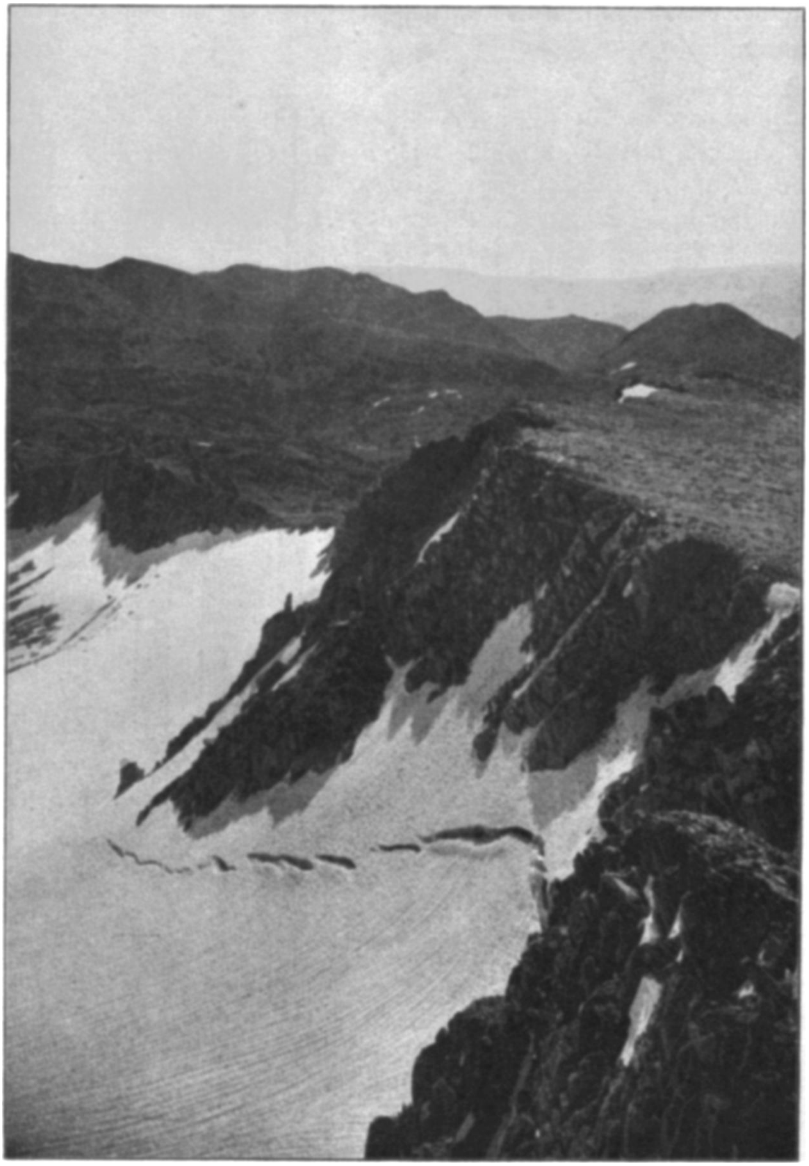

FIG. 4.—Eastward from Mount Conness, Sierra Nevada. In the foreground is the upper edge of a small glacier with its head cliff and bergschrund. Farther away the descending continuation of the same cliff springs from a schrund line, the exact position of which is masked by a lingering snow-drift.

graphs apply, the Pleistocene glaciers occupied a smaller share of the surface, and there are considerable unglaciated areas. The photograph shown in Fig. 6 was made in this region. The view is westward up the trough of a glacier. Beyond the head of this trough is another glacier trough descending westward, and the dividing ridge was partly destroyed by the head-erosion of the glaciers, so that the typical amphitheater is not shown. The south wall of the trough is steep, and shows distinct evidence of sapping. The cliff at top, being composed of thoroughly jointed granite, does not stand vertical, and the fragments recently fallen from it have built a talus which conceals the schrund line. But it is evident that here the sapping action at the schrund line was more active than the glacial erosion lower down on the slope, so as to create a sort of shoulder or terrace near that level. Stating the interpretation in another way, the excessive alimentation along the south wall of the glacier was here developing a branch glacier and a tributary cirque. This cirque was eating its way back into the ridge bounding the glacier.

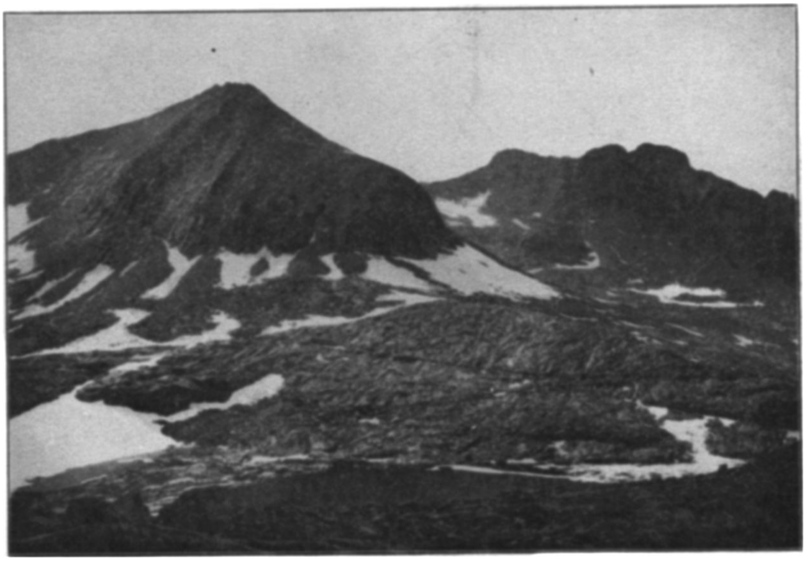

FIG. 5.—Spur between two glacial amphitheaters near Mount McClure, Sierra Nevada, showing schrund line.

On the opposite side of the ridge are gentle slopes, in part of preglacial origin. Perhaps all the portions visible are of that character, but on that side of the ridge are also faintly developed cirques, from which small ice-streams flowed toward the south.

At still lower levels are many ridges along which Pleistocene glaciers were developed on one side only—the north or northeast side, so far as observed. The south and southwest slopes retain the preglacial facies, and retain also the actual preglacial topography, except for such equable reduction of surface as may have been accomplished by aqueous and atmospheric agencies. The direction of ice movement in such cases was not parallel to the ridge axis, but approximately normal to it. The glacial excavation did not always take the character of a series of cirques, but sometimes produced a

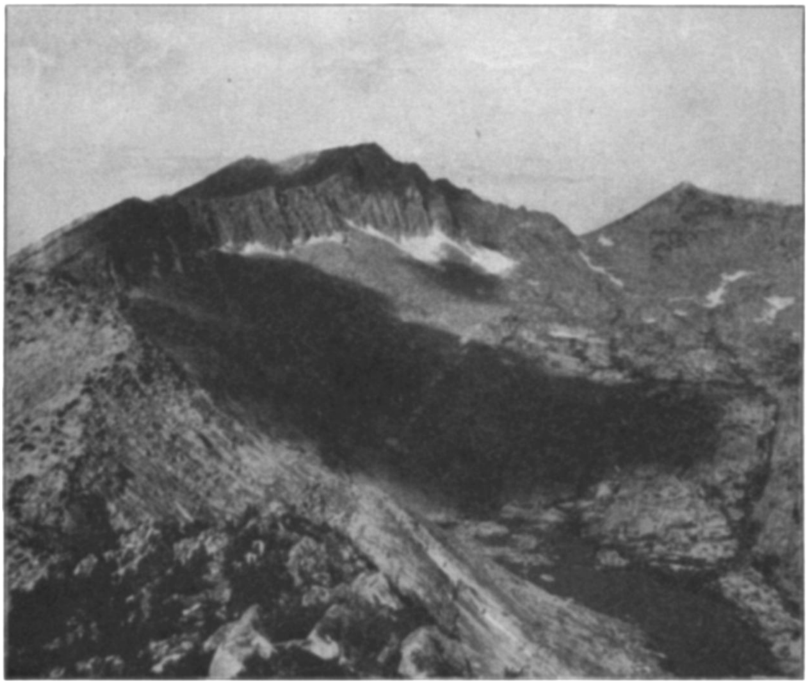

FIG. 6.—Westward from Kid Peak, Sierra Nevada. The highest point of the crest at left is Goat Peak.

continuous cliff, running with moderate undulation parallel to the ridge axis.

I have no photograph representing this topographic type in its purity. Fig. 7, exhibiting a ridge of greater altitude, serves to show a somewhat similar cliff, wrought by glacial head-erosion but imperfectly divided into cirques, and culminating in a crest from which nonglacial profiles descend in the opposite direction. But the example differs from the type in the stronger expression of the ice-work, in the comparatively high grade of the nonglacial profiles, and in the fact that those profiles, as seen in the photograph, conceal south-facing cirques of some magnitude.

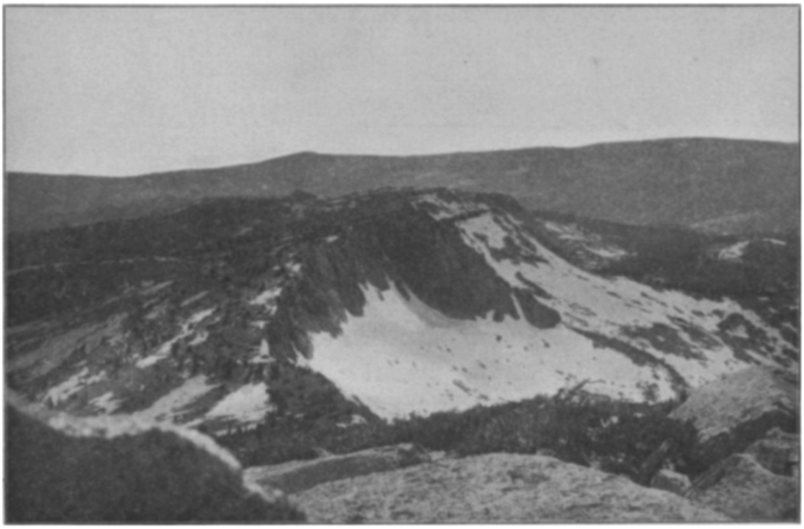

FIG. 7.—Westward from Mount Hoffmann, Sierra Nevada. Compare the glacial topography of the north (right) face of ridge, with the nonglacial profiles toward the south. [Photograph by A. C. Lawson.]

The asymmetry of these lower ridges is more pronounced than that of any others, because instead of contrasting two phases of glacial erosion they contrast glacial with nonglacial. It is worthy of note also, though not strictly germane to my subject, that the contrast in sculpture of the two ridge slopes serves to compare the efficiency of subaërial degradation with that of one phase of glacial degradation. The glaciers of these low ridges, being able to develop only on the slopes most favorable for snow accumulation, marked the lower limit of névé conditions and were the feeblest of all the Sierra glaciers. Their lives must have been short, for they could exist only when glacial conditions were at or near a maximum; they began long after, and ceased long before, the glaciers of the higher districts. The topographic features they produced were subject to the dulling influence of atmospheric and aqueous attack during both interglacial and postglacial times. And yet the degradation they accomplished was far greater than that of nonglacial agents working on the opposite sides of the same ridges—agents working not only during the same time, but during all interglacial epochs and during postglacial time. It is true that we cannot measure the nonglacial work, which consisted of a general reduction of surface without notable change of form; but whatever the amount, we may assume that it would have been the same on both slopes of the same ridge, had there been no glaciers. The visible ice-made hollows therefore represent the local excess of glacial over nonglacial degradation.

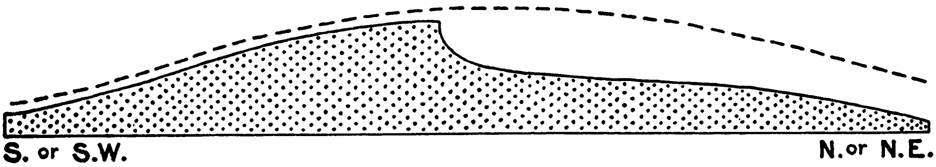

FIG. 8.—Diagrammatic cross-section of a ridge glaciated on one side only, with hypothetic profile (broken line) of preglacial surface.

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WASHINGTON, D. C.